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(71) Applicants:
- SCHLUMBERGER TECHNOLOGY B.V.
2514 JG The Hague (NL)
Designated Contracting States:
BE CH DE DK ES GR IE IT LI LU NL AT
- SERVICES PETROLIERS SCHLUMBERGER
F-75007 Paris (FR)
Designated Contracting States:
FR
- SCHLUMBERGER HOLDINGS LIMITED
Road Town, Tortola (VG)
Designated Contracting States:
GB

(72) Inventors:
- Delhomme, Jean-Pierre
92100 Boulogne Billancourt (FR)
- Anxionnaz, Herve
92320 Chatillon (FR)

(74) Representative: Menès, Catherine
Département Propriété Intellectuelle,
Etudes et Productions Schlumberger,
26, rue de la Cavée
B.P. 202
92142 Clamart (FR)

(54) A method of three dimensional reconstructing a physical magnitude inside a borehole

(57) The invention relates to a method of reconstructing a gridded three-dimensional image in the surroundings of a borehole for a first physical magnitude that is measured as a function of depth. The method comprises the steps consisting in:

- using a two-dimensional image (2) established on the wall of the borehole of a second physical magnitude measured in said borehole as a function of depth and of azimuth;
- establishing a relationship (3) between the first and second physical magnitudes; and
- deducing a gridded three-dimensional image (8) of said first physical magnitude in the surroundings of the borehole from said relationship.

It is possible to begin by using the values of the second physical magnitude as measured as a function of depth and of azimuth to deduce therefrom a gridded three-dimensional image (6) of said magnitude, and then from said image and using the relationship between the first and second physical magnitudes, to deduce the gridded three-dimensional image of the first physical magnitude in the surroundings of the borehole. The invention is applicable to measuring permeability.

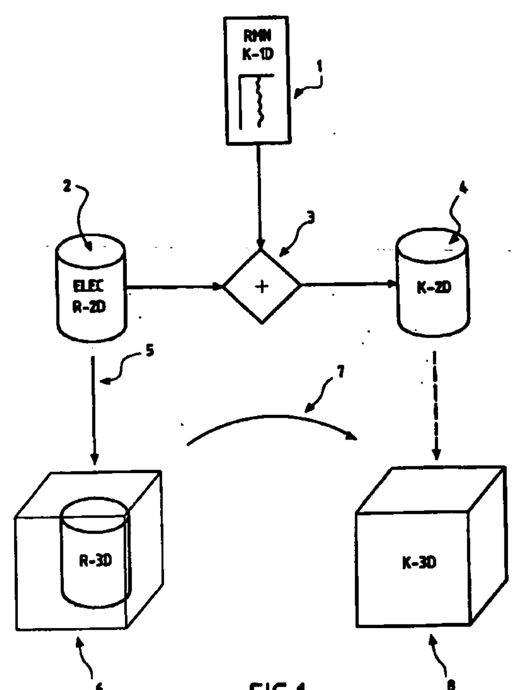

FIG.1

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Description

[0001] The present invention relates to a method of reconstructing a physical magnitude three-dimensionally in the surrounding of a borehole, and to the application of said method to integrating a plurality of sets of measurements performed in said environment.

[0002] It is already known that two-dimensional images of certain physical magnitudes, referred to below as "primary" magnitudes, can be obtained as developed over the wall of a borehole, on the basis of measurements of such a magnitude obtained at each depth in the borehole and at each azimuth. It is thus possible to reconstruct a developed image of said physical magnitude by giving a color to each pixel in a plane, defined by depth and azimuth coordinates, which color (or gray scale) is a function of the value of the physical magnitude as measured at that point.

[0003] By way of example, two-dimensional images have already been made of the electrical conductivity of the terrain surrounding a borehole, and more particularly of its resistivity in the immediate proximity of the wall of the borehole (FMI imaging). Other physical magnitudes can be envisaged, insofar as it is possible to measure them at given depth over a plurality of azimuths, as applies for example to acoustic impedance as measured by means of an ultrasound imaging device (UBI).

[0004] Nevertheless, until now such two-dimensional images have not been obtainable for certain physical magnitudes that can be measured at any given depth in a single determined azimuth only, possibly integrated over an azimuth window of varying size depending on the type of measurement. Under such circumstances, with such a physical magnitude, all that can be obtained is a curve known as a "log" showing how it varies in some given direction as a function of depth, which given direction can be fixed or otherwise.

[0005] As an example of such a "secondary" physical magnitude measured by means of a high resolution measuring device, mention can be made of density or of photoelectric factor. Mention can also be made of permeability as obtained from a nuclear magnetic resonance measuring device, or dielectric constant or wave attenuation, as recorded by means of an electromagnetic propagation measuring tool. All those measuring devices are mounted on a tool having tabs that are applied to the wall of the borehole in a given direction, and they therefore deliver for each depth increment, a value for the physical magnitude in question, as measured in said direction.

[0006] Those measurements thus suffer inherently from lack of coverage as a function of azimuth, which constitutes a limitation in formations that are heterogeneous, e.g. of the nodular, lenticular, conglomerated, fractured, or crossbedded type.

[0007] That is why proposals are made in the article "Near-wellbore 3D reconstruction of sedimentary bodies from borehole electrical image" published by H. Anxionnaz and J.P. Delhomme in the transactions of the 38th annual symposium of the SPWLA (1998), for a method of reconstructing a physical magnitude three-dimensionally in the surroundings of a borehole from a two-dimensional image of said physical magnitude as developed over the wall of the borehole.

[0008] That article relates more particularly to resistivity, with the developed image under consideration being that of resistivity in the immediate vicinity of the wall of the borehole as obtained using an FMI type tool (Schlumberger trademark: "fullbore formation microimager"), which produces an image having resolution of centimeter order.

[0009] The invention seeks firstly to provide a method making it possible to obtain a three-dimensional gridded image of a physical magnitude from linear sampling of said magnitude as a function of depth in the borehole, i.e. on the basis of a log of said magnitude, and from the two-dimensional image of some other or "primary" physical magnitude measured in the same borehole as a function both of depth and of azimuth.

[0010] The invention provides firstly a method of reconstructing a gridded three-dimensional image in the surroundings of a borehole of a first physical magnitude measured in said borehole as a function of depth, the method being characterized by the fact that it comprises the steps consisting in:

- using a two-dimensional image established on the wall of the borehole of a second physical magnitude measured in said borehole as a function of depth and of azimuth;
- establishing a relationship between the first and second physical magnitudes; and
- deducing a gridded three-dimensional image of said first physical magnitude in the surroundings of the borehole from said relationship.

[0011] In a first implementation, it is possible to begin by deducing from said relationship between the first and second physical magnitudes, values for said first physical magnitude as a function of depth and of azimuth, i.e. by deducing from said relationship a two-dimensional image over the surface of the borehole for the first physical magnitude, and then deducing from said values the gridded three-dimensional image of the first physical magnitude.

[0012] Nevertheless, a second implementation is preferable which begins by using the values of the second physical magnitude as measured as a function of depth and of azimuth, i.e. the image of said second physical magnitude developed over the surface of the borehole, to deduce a gridded three-dimensional image of said second physical magnitude, and then uses said relationship between the first and second physical magnitudes to deduce from said image the gridded three-dimensional image of the first physical magnitude in the

surroundings of the borehole.

[0013] In a particular implementation of the invention, said relationship is established in compliance with the values of at least one auxiliary physical magnitude.

[0014] More particularly, said auxiliary physical magnitude may be sampled as a function of depth and integrated over at least one azimuth range.

[0015] In particular, said auxiliary physical magnitude may be one of the magnitudes selected from porosity measured by density logging, by sound logging, or by neutron logging, and shaliness as measured by gamma radiation.

[0016] Also in a particular implementation of the invention, said relationship is established by means of an artificial neural network.

[0017] It is possible, in order to deduce the values of said secondary physical magnitude from said relationship, to apply said relationship to the values of said primary physical magnitude sampled as a function of depth and of azimuth.

[0018] The invention also provides a method of obtaining a gridded three-dimensional image of a first physical magnitude in the surroundings of a borehole, the method being characterized by the fact that it comprises the steps consisting in:

- measuring said first physical magnitude in said borehole as a function of depth;
- measuring a second physical magnitude as a function of depth and of azimuth on the wall of the borehole;
- establishing a relationship between the first and second physical magnitudes; and
- deducing a gridded three-dimensional image of said first physical magnitude in the surroundings of the borehole from said relationship.

[0019] There follows a description by way of non-limiting example of a particular implementation of the invention, described with reference to the accompanying diagrammatic drawings, in which:

- Figure 1 is an overall diagram of the method of the invention; and
- Figure 2 is a flow chart of the computation algorithm.

[0020] It can be seen in Figure 1 that the data on which the method of the invention is based is the results of two sets of measurements.

[0021] Firstly, there is a log 1 performed in a borehole, i.e. a one-dimensional reading, representing a first physical magnitude, for example in this case a log of permeability obtained by nuclear magnetic resonance measurements. By way of example, the log can be obtained using a CMR type tool (where CMR is a Schlumberger trademark: "combinable magnetic resonance").

[0022] The other set of measurements constitutes a two-dimensional image 2 over the surface of the wall of the borehole of a second physical magnitude, e.g. resistivity in the immediate vicinity of the wall. This image can be obtained by means of an FMI type tool (Schlumberger trademark: "fullbore formation microimager")

[0023] These two data sets are combined at 3, in the manner described below, so as to form a two-dimensional image 4 of the first physical magnitude over the surface of the wall of the borehole.

[0024] Thereafter, at 5, starting from the two-dimensional image 2, a three-dimensional image 6 is obtained of the second physical magnitude. For this purpose, it is possible to use the method described in the above-mentioned article "Near-wellbore 3D reconstruction of sedimentary bodies from borehole electrical images".

[0025] Finally, on the basis of this three-dimensional image 6 of the second physical magnitude, and from the two-dimensional image 4 of the first physical magnitude, the three-dimensional image 8 of the first physical magnitude is obtained at 7 in the manner described below. It will be seen that there is no need to reconstruct the two-dimensional image 4 of the first physical magnitude, but that it suffices to establish a relationship between the first and second physical magnitudes.

[0026] It should also be observed that it is possible to obtain the three-dimensional image 8 of the first physical magnitude from its two-dimensional image 4 in the same manner as the three-dimensional image 6 of the first physical magnitude is obtained from its two-dimensional image 2. Nevertheless, problems of resolution associated with the various images make it preferable to pass via the three-dimensional image 6 of the first physical magnitude and via the step 7.

[0027] The method is described below in greater detail with reference to Figure 2.

[0028] Starting from the developed two-dimensional image 20 of the electrical conductivity of the ground surrounding the borehole, as obtained by FMI imaging, the first step 21 consists in defining hydrodynamic units. A hydrodynamic unit is defined as a geological unit liable to have hydrodynamic properties that are coherent.

[0029] Sedimentary structures deposited under the same transport conditions generally present particular geometrical characteristics associated with sediment transport direction. New transport conditions give rise to a new hydrodynamic unit.

[0030] Methods enabling hydrodynamic units to be defined are well known to the person skilled in the art.

[0031] The second step 23 consists in three-dimensional reconstruction of the shapes of the sedimentary structures around the borehole in the manner described in the above-specified article "Near-wellbore 3D reconstruction of sedimentary bodies from borehole electrical images". That deterministic modeling of the shapes of sedimentary structures based on dip data derived from

the FMI image of the borehole contribute to discovering the directions of local aniosotropy in the three-dimensional distribution of conductivity (along and across the strata), and guides the following step of stochastic modeling.

[0032] The third step 24 consists in using stochastic modeling to simulate a three-dimensional distribution of electrical conductivity in the vicinity of the borehole.

[0033] For each hydrodynamic unit, the variation in three dimensions of electrical conductivity is initially characterized on the basis of the FMI data by means of a correlation function (i.e. by means of a variogram), after a logarithmic transform has been applied to the FMI data so as to compensate for its distribution being log-normal in the statistical sense. The correlation function is calculated both in the direction of the stratification and across it. Normally, it differs from one hydrodynamic unit to the next.

[0034] The correlation functions calculated for each hydrodynamic unit are then used to perform conditional stochastic simulation of electrical conductivity around the borehole to satisfy simultaneously the shape of the deposits as obtained in the second step 23, and the conductivity data as recorded from the wall of the borehole.

[0035] The simulation is performed for each point in three dimensions by using a correlation function with specific directions of aniosotropy as deduced from the deterministic model 23, and by using a specific anisotropy ratio deduced from analyzing the directional correlation. In practice, the distribution of the geometrical mean of electrical conductivity in 15 cm × 15 cm × 15 cm cells is simulated at 25 so as to provide a first change of scale so as to come closer to the resolution of a nuclear magnetic resonance CMR tool.

[0036] Essentially, steps 23 and 24 can be summarized as follows.

[0037] Initially (step 23), the values of a certain number of geometrical parameters (angles, distances, ...) are determined point by point within a certain volume around the borehole so as to satisfy the dip data at the wall of the borehole as obtained by the conductivity measurements. This determination can be performed in the manner described in Appendix A of the above-mentioned article.

[0038] Thereafter (step 24), variation in electrical conductivity at the wall of the borehole is determined initially both along and across the dip. This conductivity data is then exported to the entire volume surrounding the borehole, taking account of the variations in the parameters as determined in step 23. Appendix B of the above-specified document describes an algorithm enabling the problem of step 24 to be solved.

[0039] The result 26 of the preceding steps is a three-dimensional electrical conductivity grid made up of cube-shaped cells of side equal to 15 cm and describing a parallelepiped of 1 m × 1 m × N m centered on the axis of the borehole.

[0040] The purpose of the fourth step is to prepare for transforming electrical conductivities into permeability.

[0041] Firstly, texture logs 27 are optionally deduced from the FMI images 20 after dip compensation has been performed in 28, if necessary, for structural tilt. These texture logs contain additional information which is necessary for establishing the best relationship between permeability and electrical conductivity. It may be observed that a method of establishing such a relationship is described in French patent application No. 98 16614.

[0042] In addition to the two-dimensional resistivity image 20, the following are also available for establishing this relationship: volumetric logs 29 of auxiliary magnitudes such as porosity as measured by density logging, by sound logging, or by neutron logging, and also shaliness as measured by gamma radiation. Also available are CMR measurements 30 obtained by nuclear magnetic resonance.

[0043] Given the azimuth of the CMR sonde, it is necessary firstly to deduce a conductivity curve 31 from the FMI electrical images at the resolution of the nuclear magnetic resonance measurements, in alignment with the azimuth of the measurements. This is azimuth-matching step 32.

[0044] During this step, the volumetric logs 29 of the auxiliary data are also accurately aligned in depth with the permeability curve deduced from the nuclear magnetic resonance measurements and with the conductivity curve that is matched in resolution and azimuth as deduced from the FMI images.

[0045] An artificial neural network is then created at 35 and a stage of training the network makes it possible to establishes a relationship 36 between the permeability deduced from the nuclear magnetic resonance measurements and the electrical conductivity deduced from the FMI measurements, in compliance with volumetric logs of gamma ray porosity and of transit time, and optionally with texture logs deduced from images of the borehole are available.

[0046] The fifth step consists in converting the three-dimensional electrical conductivity grid into a permeability grid.

[0047] To this end, the above-mentioned relationship obtained by means of the artificial neural network is applied at 37 to each cell of the three-dimensional conductivity grid so as to deduce a three-dimensional permeability grid 38 therefrom at the resolution of the measurements performed by nuclear magnetic resonance.

[0048] The result can be used in 39 to prepare a campaign of downhole tests by means of a formation test tool (such as Schlumberger's tool known by the trademark MDT: "modular formation dynamics tester), by making an <u>a priori</u> model of fluid flow based on the three-dimensional permeability grid. Use of the tool can thus be optimized.

[0049] The result can also be used to compare horizontal and vertical permeability data K_h and K_v obtained by an MDT test (at meter scale) with information supplied by the logging images (at centimeter scale) and with the permeabilities obtained by means of the invention using nuclear magnetic resonance (at decimeter scale).

[0050] These various types of data can initially be adjusted at 41 by matching the aniostropy parameters of the stochastic model when the values of anisotropy (K_h/K_v) differ from one type of data to another.

[0051] They can also be adjusted in 42 by modifying the coefficients in the formulae for interpreting the nuclear magnetic resonance data when the values of $[K_h * K_v]^{1/2}$ differ from one type of data to another. More specifically, the coefficient C of Kenyon's formula is adjusted, e.g. as given in the article "Nuclear magnetic resonance imaging - technology for the 21st century", published by B. Kenyon and G. Gubelin, in the journal *Schlumberger Oil Review*, Autumn 1995.

Claims

1. A method of reconstructing a gridded three-dimensional image in the surroundings of a borehole of a first physical magnitude measured in said borehole as a function of depth, the method being characterized by the fact that it comprises the steps consisting in:

    - using a two-dimensional image (2) established on the wall of the borehole of a second physical magnitude measured in said borehole as a function of depth and of azimuth;
    - establishing a relationship (3) between the first and second physical magnitudes; and
    - deducing a gridded three-dimensional image (8) of said first physical magnitude in the surroundings of the borehole from said relationship.

2. A method according to claim 1, which begins by deducing from said relationship between the first and second physical magnitudes, values (4) of the first physical magnitude as a function of depth and of azimuth, and then deduces the gridded three-dimensional image of the first physical magnitude from this values.

3. A method according to claim 1, which begins by using the values of the second physical magnitude as measured as a function of depth and of azimuth to deduce a gridded three-dimensional image (6) of said second physical magnitude, and then said relationship between the first and second physical magnitudes is used to deduce from said image the gridded three-dimensional image of the first physical magnitude in the surroundings of the borehole.

4. A method according to any one of claims 1 to 3, in which said relationship is established in compliance with the values of at least one auxiliary physical magnitude (29).

5. A method according to claim 4, in which said auxiliary physical magnitude is sampled as a function of depth and integrated over at least one azimuth range.

6. A method according to claim 5, in which said auxiliary physical magnitude is one of the magnitudes selected from porosity measured by density logging, by sound logging, or by neutron logging, and shaliness as measured by gamma radiation.

7. A method according to any one of claims 1 to 6, in which said relationship is established by means of an artificial neural network.

8. A method according to any one of claims 1 to 7, in which, in order to deduce the values of said secondary physical magnitude from said relationship, said relationship is applied to the values of said primary physical magnitude sampled as a function of depth and of azimuth.

9. A method according to any one of claims 1 to 8, in which said first physical magnitude is permeability.

10. A method according to any one of claims 1 to 9, in which said second physical magnitude is resistivity.

11. A method of obtaining a gridded three-dimensional image of a first physical magnitude in the surroundings of a borehole, the method being characterized by the fact that it comprises the steps consisting in:

    - measuring said first physical magnitude in said borehole as a function of depth;
    - measuring a second physical magnitude as a function of depth and of azimuth on the wall of the borehole;
    - establishing a relationship (3) between the first and second physical magnitudes; and
    - deducing a gridded three-dimensional image (8) of said first physical magnitude in the surroundings of the borehole from said relationship.

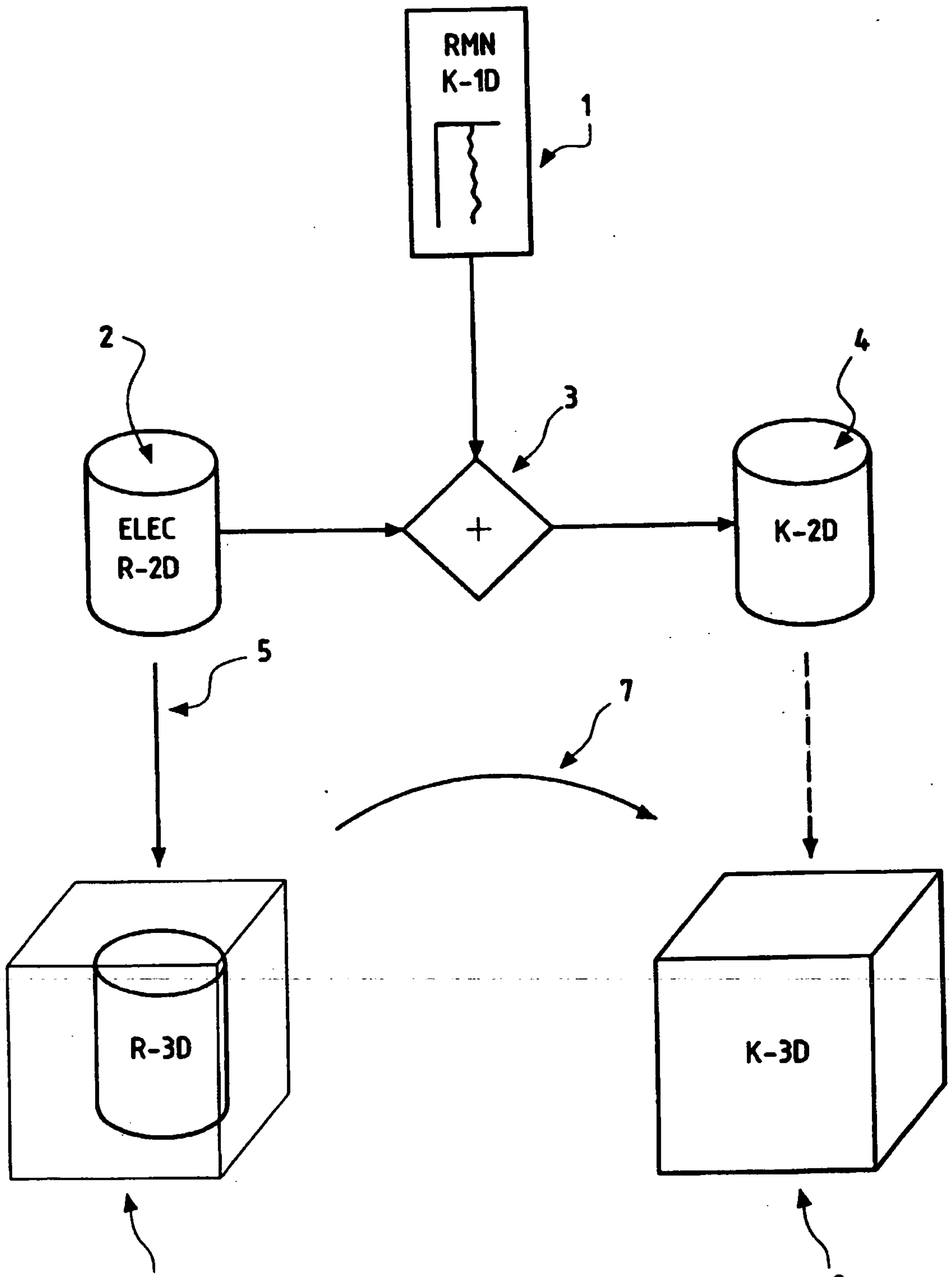
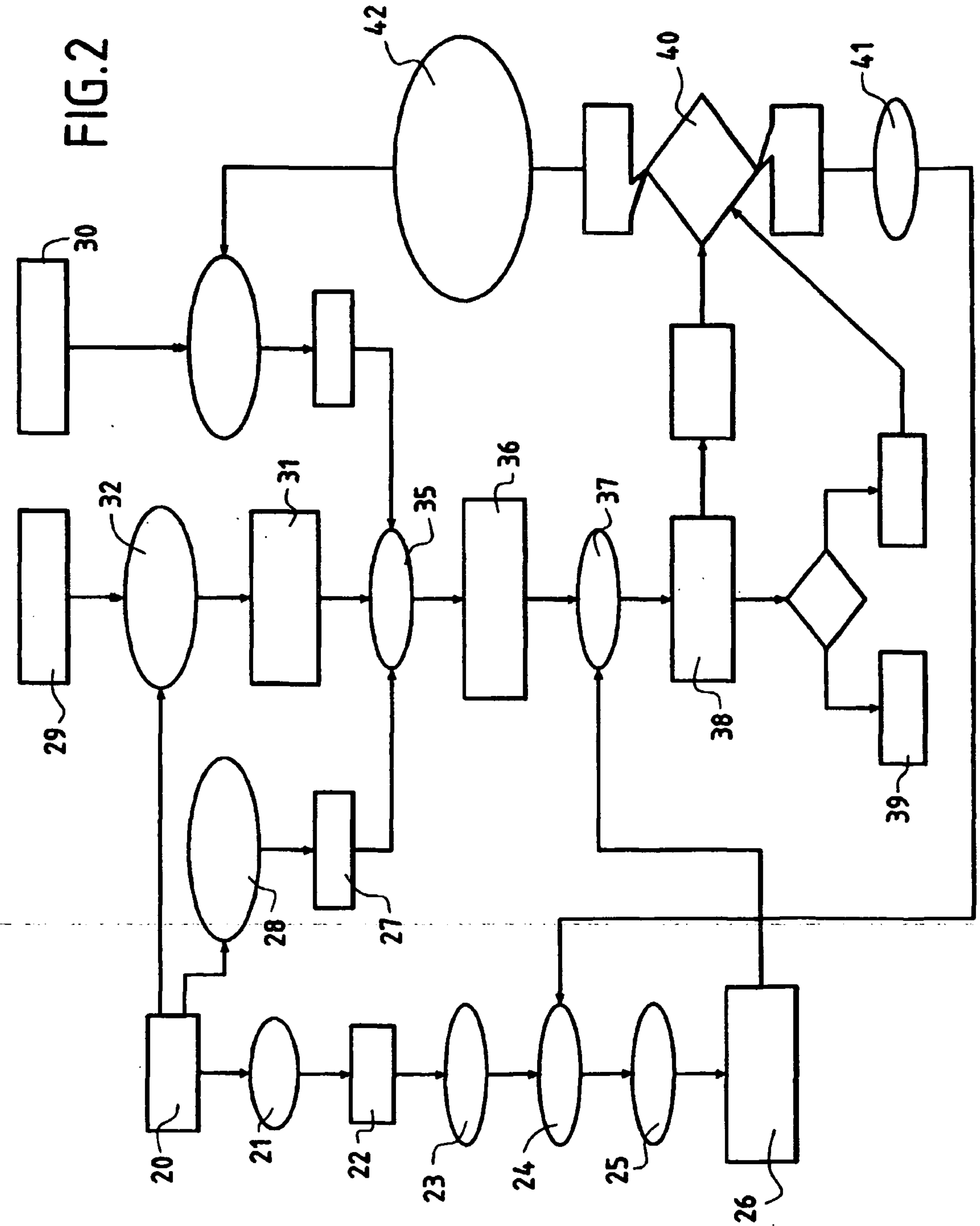


FIG.1

FIG.2



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EUROPEAN SEARCH REPORT

Application Number
EP 00 20 2401

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Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int.Cl.7)
A	DELHOMME J P ET AL: "Permeability and porosity upscaling in the near-wellbore domain: The contribution of borehole electrical images" PROCEEDINGS OF THE 1996 EUROPEAN PETROLEUM CONFERENCE. PART 1 (OF 2);MILAN, ITALY OCT 22-24 1996, vol. 1, 1996, pages 89-101, XP002137098 Richardson, TX, USA * abstract * * page 89, column 2, line 9 - page 90, column 1, line 28 * * page 93, column 2, line 3 - line 38 *	1,11	G01V11/00
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A	EP 0 561 492 A (TEXACO DEVELOPMENT CORP) 22 September 1993 (1993-09-22) * abstract; claim 2 *	1,7	

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The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
THE HAGUE	17 October 2000	Lorne, B

CATEGORY OF CITED DOCUMENTS

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EUROPEAN SEARCH REPORT

Application Number
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TECHNICAL FIELDS SEARCHED (Int.Cl.7)

The present search report has been drawn up for all claims

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